AFRL-SR-BL-TR-98-

0540

REPORT DOCUMENT[ATION PAGE]

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Final 01 Oct 95 to 30 Sep 97

4. TITLE AND SUBTITLE
Extension of UCLA JSEP program in Millimeter Wave Electronics

5. FUNDING NUMBERS
61102F
2301/FS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
110 Duncan Aven RmB115
Bolling AFB DC 20332-8050

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-96-C-0002

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVAL FOR PUBLIC RELEASED: DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Publications based on Research accomplishments of JSEP program at UCLA is reported for the period shown above. The program consists of 5 research units. This is the only JSEP program emphasizing the millimeter-wave electronics. By synergistic effort among these five units specializing solid state electronics, device theory, electromagnetic analysis and millimeter wave circuit and wave interaction, optically assisted millimeter wave integration, this JSEP program is intended to address many bottleneck issures that prevent widespread use of this part of electromagnetic spectrum.

19980730 146

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

DIRECTOR'S OVERVIEW

This report is for the second year after the program modification was approved and two new units were included (Unit 3, Prof. Jalali and Unit 5, Prof. Wu). At the same time, this report coincides with the initiation of the phase out plan implemented by the TCC decision. Therefore, in one hand, the program needs to be stronger while on another the extent of the program needs to be maintained in a manageable size to prepare for the phase out that takes place over the next 12 month period. For this reason, all units have made efforts to complete as many projects before the closure of the program and to time the remaining effort.

In the past, findings from research effort has been included in renewal proposal to TCC. However, all of the unit investigators are now making an effort to find other funding opportunities. Nevertheless, the research effort for JSEP has not been jeopardized by such effort in the opinion of this author. All units are continued to be active in the respective tasks as the only JSEP program specializing in millimeter wave electronics in the nation.

Tatsuo Itoh

Unit 1 (Professor K. L. Wang)

The projects carried out in Unit 1 are: (1) Microwave properties of series-connected resonant tunneling diodes (RTDs), (2) Transport properties and energy band analysis in a RTD, and (3) Difference frequency generation (DFG) in a quantum well waveguide structure. Research continued into the transport properties of RTDs with emphasis focussed on explaining why current peaks are observed when the energy bands of the quantum wells are aligned with the emitter energy levels rather than with the connected wells as expected. In addition, structures were designed to have series connected RTDs operate in the negative differential resistance (NDR) region simultaneously. In this way, the output microwave power could be enhanced dramatically. Ideally, this would occur by controlling the bias voltage on each RTD separately, but given the thicknesses of the layers involved, this is not yet possible with today's technology. By optimizing the spacer layers and drift regions between the RTDs, however, improvements in simultaneous operation were achieved. S-parameter characterization of the RTDs also continued with maximum operating frequencies of greater than 16 GHz achieved with the InGaAs/AlAs structure. In addition RTDs using GaN material, which were provided by an outside manufacturer, were investigated, and attempts to obtain NDR data were made. It was found that the material quality of these devices was not good enough to support NDR operation. Attempts are currently underway to improve the material properties and achieve NDR in these devices. DFG research in the IR region was concluded and the current emphasis is on producing long wavelength signals. A bolometer has been contracted in order to detect the long wavelength signals which are expected to be generated. Theoretical studies of the propagation of optical and millimeter waves through various types of semiconductor waveguide structures has been conducted. Since two separate lasers of sufficient power at the wavelength of interest are not available, research has been conducted by splitting the output of a single mode locked Ti:sapphire laser into two component parts which are then separately filtered using narrowband filters into two fields with wavelengths which are separated by 10 nm. In this manner, an output signal with a wavelength of approximately 81 □m should be generated. The laser is easily tunable over a wide range, so the output power can be monitored while varying the input fields around the fundamental absorption edge of GaAs in order to examine the trade-offs between resonance enhancement and losses due to absorption and maximize the output power. The overall goal of this unit remains to create viable energy sources in the millimeter wave region.

List of Publications

1. J. Jo, K. Alt, and K.L. Wang, "Observation of new type resonances in triple barrier resonant tunneling diodes," J. Appl. Phys. 82 (6), 15 September 1997.
2. J. Jo, K. Alt, and K.L. Wang, "Effect of doping density on capacitance of resonant tunneling diodes," to appear in J. Appl Phys., in a November 1997 edition.
3. J. Jo, Y.I Choi, D.M. Kim, K. Alt, and K.L. Wang, "Observation of resonances by individual energy levels in InGaAs/AlAs triple barrier resonant tunneling diodes," submitted to Appl. Phys. Lett. July 1997.

Post Doctoral
    Kevin Wang
    Richard Li
Graduate Students
    Kevin Alt
Technology Transfer
None
Invention
None
Honors and Awards, Advisory Functions
None

Unit 2 (Professor D. S. Pan)

The objective of Unit 2 is to provide theoretical support for conception and modeling new ways of generating millimeter and submillimeter waves. Three primary directions have been pursued in this period. (1) Explore and analyze new structural concepts for millimeter and submillimeter source devices. (2) Develop a complete theory of subfrequency excitation for series integrated RTD oscillator. (3) Provide optical interaction analysis for other Units and explore new distributed mechanisms in quantum structures for millimeter and submillimeter wave generation.

(1) We have continued our investigation of the high frequency capability of heterojunction bipolar transistors (HBTs). It is inevitable that high current density is required for high frequency operation. We have analyzed a special high current density effect that causes a delay of Kirk effect due to the collector current spreading. This is related to the recent efforts of making HBT power source from small dot structures. Experimental evidence of the effect has been observed by collaboration with Rockwell Science Center. A preliminary account of the results has been published in Electron Device Letters. In further analysis of the carrier transit time effects in both the base and collector, we have conceived and analyzed a new device called BITT (Bipolar Injection and Transit Time) device. We have almost worked out a preliminary small signal and large signal theory for BITT. It will work in the frequency range of 200 to 800 GHz with an average efficiency of about 20%. A more detailed account is presented in the significant accomplishments. We have also continued our exploration of using interband tunneling for transistors at millimeter and submillimeter wave frequencies. This is also a new idea and many optimizations of the transistor design need to be done. We have made slow but good progress in analyzing the transconductance and input capacitances. The performance of the device is being compared with HEMT.

(2) We have successfully completed an analytical theory for the subfrequency excitation. The theory provides a basis for our understanding of the excitation process. The complete theory shows a new concept of a *parametric oscillator.* In the theory, the negative resistance of series-connected RTDs can be viewed as a parametric function of the excitation pulse. (Mathematically, it is a functional of the terminal voltage). In such fashion, the theory clearly shows how the high frequency oscillation is built up by seeing the appropriate negative resistance of the series integrated negative resistance diodes (RTDs in this case) excited by a low frequency pulse. The theory will provide simple guidance and quantitative design principle for series integrated RTDs. It is being written up.

(3) We have done some preliminary analysis of photodiodes. We will continue the simulation for photodiodes once we have completed the transistor simulation. We have completed our preliminary calculation of quantum levels in the quantum dots and are in the process of evaluating the electron life time in the quantum dots due to phonon scattering.

List of Publications

1. P. J. Zampardi and D. S. Pan, "Delay of Kirk Effect Due to Collector Current Spreading in Heterojunction Bipolar Transistors", IEEE Electron Device Lett. Vol. 17, pp 470-472, Oct. 1996.

List of personnel (faculty, post doc and grad students in your unit)
Faculty
D. S. Pan
Post Doctoral
X. Zhang
Graduate Students
A. Man, H. Li, and L. Chen
Technology Transfer
None
Invention
None

Honors and Awards, Advisory function to government
None

Unit 3 (Professor B. Jalali)

During this period Unit 3 explored the use of photonic technique for microwave signal processing. The objective is to overcome the electronic bottleneck by exploiting unique properties of photonics. Filters represent one of the most challenging components of a typical communication or radar system. An example of the importance and impact of high Q filters is in a moving target indication radar. To identify a moving target, a radar must distinguish a weak Doppler shifted target echo from a large background (the clutter). In conventional systems the clutter is eliminated using a notch filter implemented after the A/D conversion in the digital domain. As the input to the A/D contains both the small echo and the large clutter, the A/D must attain 14-18bit dynamic range, a feat that is increasingly difficult at I.F. and RF frequencies required in the emerging direct conversion receivers. If the notch filter could be implemented in the analog domain, the clutter is reduced before the A/D conversion, and hence the dynamic range requirement is reduced. For example, if the clutter can be suppress by 30dB, the required dynamic range is reduced by 5bits. Optical transversal filters have the potential to deliver high Q at microwave frequencies. There are two methods for imposing the microwave signal on an optical carrier: intensity modulation and electric field modulation. To avoid problems with optical interference resulting in unstable filter response, intensity modulation is the preferred method. However, as intensity is a positive quantity, it has been impossible to subtract two signals. This is a fundamental problem that has hindered the implementation of optical transversal filters. We have developed a novel technique by which two intensity modulated optical signals can be subtracted in an all-optical fashion. To accomplish this, we exploit cross gain modulation in a semiconductor laser gain medium. An intensity modulated laser beam and a CW beam from a second laser are incident on the semiconductor optical amplifier (SOA). The intensity modulated beam with wavelength L1 modulates the gain that is experienced by the second laser beam of wavelength L2. Therefore the information is copied onto the CW beam. As the intensity L1 increases, it causes stimulated emission depleting the population inversion and hence reducing the gain. Hence The modulation on L2 is thus the inverse of the original signal on L1. It is imperative to note that this inversion, or pi phase shift occurs for all modulation frequencies and is truly broadband. In our prototype two tap transversal filter, a laser beam intensity modulated with the microwave signal is split in two, one half is inverted and is added to the second half, resulting in subtraction of the intensity modulation. Even with the simple experiment, a suppression of 30dB was achieved demonstrating the fidelity of this technique. This work represents the first realization of a negative tap in an optically incoherent system. It can be the basis for realizing photonic-microwave filters with diverse and tailored response functions.

List of Publications

(1) F. Coppinger, S. Yegnanarayanan, P.D. Trinh, and B. Jalali, "Non-recursive tunable photonic filter using wavelength-selective true-time-delay," IEEE Photonic Technology Letters, vol. 8, no. 9, pp. 1214-1216, 1996.

(2) F. Coppinger, S. Yegnanarayanan, P.D. Trinh, B. Jalali, "Continuously tunable photonic notch filter," IEEE Photonic Technology Letters, vol. 9, no. 3, pp. 339-341, 1997.

(3) F. Coppinger, S. Yegnanarayanan, P.D. Trinh, B. Jalali " All optical incoherent negative taps for photonic signal processing," Electronic Letters, vol. 33, no. 11, pp. 973-975, 1997.

List of Personnel
Faculty
Bahram Jalali
Postdoctoral Researcher

Fred Coppinger
Graduate student
S. Yegnanarayanan
Technology Transfer

Inventions
None

Honors and Awards, Advisory Functions:
Prof. Jalali was invited to the Naval Surface Warfare Center NSWC's Crane Division in Indiana on August 7th, to brief NSWC on his research in microwave photonics. A prototype true time delay device, developed by his group is currently being evaluated by NSWC for possible use in the Aegis system.

Motorola's Space Science Division in Tempe Arizona has expressed interest in Prof. Jalali's research on microwave photonics. He has been invited to visit the company and brief them on his research on September 16th.

Unit 4 (Professor T. Itoh)

Unit 4 continued to work on the electromagnetic interactions of the devices and circuits. During this period, three topics have been investigated. (1) Active leaky wave antenna as a ring-laser type oscillator, (2) electronic control of Yagi-Uda antenna for surface waves, and (3) electromagnetic simulation of active circuits.

(1) In the previous period, we have accomplished an active insertion into a leaky wave antenna so that the antenna gain is enhanced. Following this finding, we have investigated a nonreciprocal nature of the active antenna. This is a new research area and needs to be investigated by a sizable basic research program hoped to be available in the future. In the mean time, the leaky wave antenna with an active device are used for developping a feedback type oscillator. (2) The objective of this project is to control electronically the radiation characteristics of a Yagi-Uda slot antenna for surface wave launcher. By loading the parasitic slot with reactance generated by FET with appropriate bias, the electrical length of the parasitic slot can be controlled so that the radiation characteristics have been changed. (3) The extended FDTD (Finite Difference Time Domain) method was applied this time for a balanced mixer. The nonlinear characteristics of the devices have been included in the electromagnetic field analysis by FDTD.

List of Publications

1. L. Y. Lin, M. C. wu, T. Itoh, T. A. Vang, R. E. Muler, D. L. Sivco and A. Y. Cho, "Velocity-matched distributed photodetectors with high-saturation power and large bandwidth," IEEE Photonics Tech. Lett., vol.8, no.10, pp.1376-1378. October 1996.

2. C.-N. Kuo, B. Houshmand and T. Itoh, "Full-wave analysis of packaged microwave circuits with active and nonlinear devices: an FDTD approach," IEEE Trans. Microwave Theory Tech., vol.45, no.5, pp.819-826, May 1997.

3. "High-Power High-Speed Photodetectors - Design, Analysis and Experimental Demonstration," IEEE Trans. Microwave Theory and Techniques, Vol.45, No.8, pp.1320-1331, August 1997 (L. Y. Lin, M. C. Wu, T. Itoh, T. A. Vang, R. E. Muller, D. L. Sivco, and A. Y. Cho).

List of Personnel

Faculty
T. Itoh
Post Doctoral
Y. Qian
Graduate Students
W. Fu, M. Chen and C.-N. Kuo

Technology Transfer

T. Itoh was visited by Dr. Paul Greiling of Hughes Research Laboratory on April 29, 1997 and presented his research programs including the accomplishments under JSEP.

Dr. B. Perlman of ARL visited T. Itoh on April 8, 1997 and discussed research projects.

Invention
None
Honors and Award, Advisory Functions
T. Itoh organized Topical Symposium on Millimeter Waves at Shonan Village, Hayama, Japan, sponsored by AFOSR Far East Office in Tokyo (Dr. S. Fujishiro in charge) on July 7-8, 1997. This symposium was attended by more than 100 participants from Japan, Europe and US. Co-chair was Dr. R. T. Kemerley of WL/AAD.

Unit 5 (Professor M. C. Wu)

Unit 5 focuses on the use of ultra-wideband optoelectronics to extend the frequency limit of millimeter-wave devices, and to assist the integration/functionality of millimeter-wave integrated circuits. Three topics have been investigated during this period. (1) Experimental and theoretical investigation of high power, high frequency photodetectors; (2) Wavelength-division-multiplexing (WDM) technique for microwave photonic systems.

(1) High power photodetectors are required to realize high RF gain, large signal-to-noise ratio, and high dynamic range for microwave photonic photonic systems. Last year, we have demonstrated a GaAs/AlGaAs velocity-matched distributed photodetectors (VMDP), and achieved record performance. This year, we have extended the concept to long wavelength (1550 nm) for fiber distribution of millimeter-waves and antenna remoting. A new metal-semiconductor-metal (MSM) with InGaAs absorption layer (lattice-matched to InP) and InAlAs/InGaAs graded superlattice barrier enhancement layer has been demonstrated. Extremely good dark current performance (200 pA) has been obtained using a special surface treatment for Schottky contact. The RF characteristics of the long-wavelength VMDP has been measured. The device maintains nearly 50 ohm characteristics and low RF insertion loss from .1 to 50 GHz. Beam propagation method has also been used to simulate the optical property of the VMDP. The bandwidth of the VMDP is now being characterized.
(2) We have investigated the application of the wavelength (WDM) techniques in millimeter-wave photonic systems. We have achieved two major accomplishments this year: (a) We proposed a novel WDM source to overcome the fundamental limit of millimeter-wave photonic systems due to the relative intensity noise (RIN) of the laser source. The signal-to-noise ratio and dynamic range of millimeter-photonic systems are currently limited by the RIN of semiconductor laser source. By using a multi-wavelength WDM laser source and a single modulator, the RIN noise added out-of-phase while the millimeter-wave signals add in-phase when the multi-wavelength signals are combined at the photodetector. Up to 18 dB improvement in signal-to-noise ratio and 12 dB improvement in dynamic range can be improved by employing 64 wavelengths. (b) We have experimentally demonstrated a multi-wavelength optically controlled phased array antenna (MWOCPAA) receiver. Broadband phased array antennas with broad bandwidth and squint-free operation are highly desirable. Optics offers significant advantage for implement such phased array antennas. Up to now, most of the results reported in literature focus on transmitters. Receiver has been a bottleneck for most implementations. We have proposed and experimentally demonstrated a novel MWOCPAA concept that have solved the

fundamental difficulty in realizing broadband receivers. A 2-element receiver prototype with DC-5 GHz bandwidth has been experimentally demonstrated.

List of Publications

Journals

J1. D. T. K. Tong and M. C. Wu, "Continuously Tunable Optoelectronic Millimeter-Wave Transmitter Using Monolithic Mode-Locked Semiconductor Laser," Electronics Letters, Vol. 32, No. 17, pp. 2006-2007, October 1996.

J2. L. Y. Lin, M. C. Wu, T. Itoh, T. A. Vang, R. E. Muller, D. L. Sivco, and A. Y. Cho, "Velocity-Matched MSM Distributed Photodetectors with High Saturation Power and Large Bandwidth," IEEE Photonics Technology Letters, Vol. 8, No. 10, pp. 1376-1378, October, 1996.

J3. L. Y. Lin, M. C. Wu, T. Itoh, T. A. Vang, R. E. Muller, D. L. Sivco, and A. Y. Cho, "High-Power High-Speed Photodetectors - Design, Analysis, and Experimental Demonstration," IEEE Transaction on Microwave Theory and Techniques, Vol. 45, No. 8, August 1997.

Conferences

C1. M. C. Wu and D. T. K. Tong, "Two-Dimensional Multi-Wavelength Optically Controlled Phased Array Antennas," Allerton Antenna Conference, University of Illinois, September 18-20, 1996.

C2. * L. Y. Lin, M. C. Wu, T. Itoh, T. A. Vang, R. E. Muller, D. L. Sivco, and A. Y. Cho, "High Speed Photodetectors with High Saturation for High Performance Microwave Photonic Systems," International Topical Meeting on Microwave Photonics, Kyoto, Japan, December 3-5, 1996 (Invited Talk).

C3. * M. C. Wu, T. Itoh, and L. Y. Lin, "Progress in High Power, High Frequency Photodetectors," 1997 Progress in Electromagnetics Research Symposium (PIERS '97), Hong Kong, January 6-9, 1997, (Invited Talk).

C4. * M. C. Wu, D. T. K. Tong, and J. C. Brock, "Fiber Grating Programmable Dispersion Matrix for Two Dimensional Multiwavelength Optically Controlled Phased Array Antennas," 7th Annual Symposium on Photonic Systems For Antenna Applications (PSAA-7), Monterey, CA, January 13 - 16, 1997 (Invited Talk).

C5. L. Y. Lin, M. C. Wu, T. Itoh, T. A. Vang, R. E. Muller, D. L. Sivco, and A. Y. Cho, "High Power, High Speed Velocity-Matched Distributed Photodetectors," Proc. Optoelectronic Integrated Circuits, SPIE Photonics West, San Jose, CA, February 9-14, 1997.

C6. L. Y. Lin, M. C. Wu, and T. Itoh, "Figure of Merit for High-Power, High-Speed Photodetectors," 1997 Optical Fiber Communications (OFC) Conference, Dallas, Texas, February 16-21, 1997.

C7. D. T. K. Tong and M. C. Wu, "Multiwavelength Microwave Photonic Systems: Beyond Fundamental RIN-Limited Performance," 1997 Conference of Lasers and Electro-Optics (CLEO), Paper CWN4, Baltimore, Maryland, May 18 - 23, 1997.

C8. * M. C. Wu, "High Frequency Photodetectors with High Saturation Photocurrent," Annual Meeting of Optical Society of America, Long Beach, California, October 12-17, 1997 (Invited Talk).

C9. * M. C. Wu, "Travelling-Wave Photodetectors," IEEE LEOS Annual Meeting, San Francisco, CA, November 10-13, 1997 (Invited Talk).

List of Personnel
Faculty
M. C. Wu
Graduate Students
Dennis T. K. Tong, Tai Chau, Andrew Rollinger
Undergraduate Student

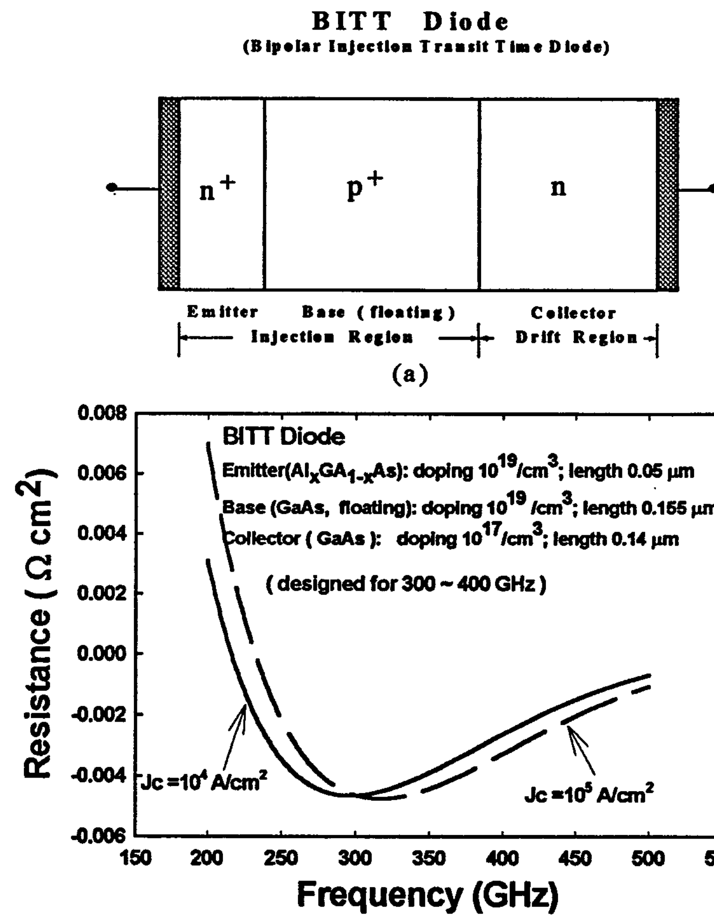
Sagi Mathai

A New Submillimeter Source:BITT

L. Chen, D. S. Pan

UCLA JSEP 1997

- Bipolar injection localizes injected carriers
- Much better than IMPATT at deep millimeter and submillimeter frequencies
- Floating Base gives additional 90 degree phase delay with efficiency about 20%
- Better than RTD, no spurious oscillation
- Worked out a small signal and preliminary large signal theory



(a)

(b)

<u>**A New Millimeter and Submillimeter Wave Device**</u>
<u>**Bipolar Injection Transit Time Device (BITT)**</u>

L. Chen and D. S. Pan

We have investigated and just worked out a general theory of a new millimeter and submillimeter wave device named BITT (Bipolar Injection and Transit Time). The device is similar to a HBT (Heterojunction Bipolar Transitor) structure with a relatively long floating base as shown in Fig. 1a. The base transit time is utilized to introduce a phase delay close to 90 degree. Both a small signal theory and a preliminary large signal theory have been worked out. The small signal negative resistance of a BITT designed for 300-400 GHz is calculated as shown in Fig. 1b. The highest effciency of the device is estimated to be 20 % in these submillimeter wave frequencies. We estimate that BITT can work into deep submillimeter wave frequencies as high as 700 GHz.

In comparison with other semiconductor devices above 200GHz, BITT has many outstanding advantages. IMPATT has an effciency smaller than 5%. This is mainly due to the saturation of ionization coefficient that the impact ionization injection cannot be localized. All submillimeter wave IMPATTs are basically therefore Misawa type (distributed carrier injection). The neutral base region of the BITT perfectly localizes the carrier injection into the drift region (collector). RTD has an efficiency of about 10% in the submillimeter wave frequencies. In comparison, BITT has no spurious oscillation problem and therefore much easier to have more power for one device and also easy to have device level integration in series connection.

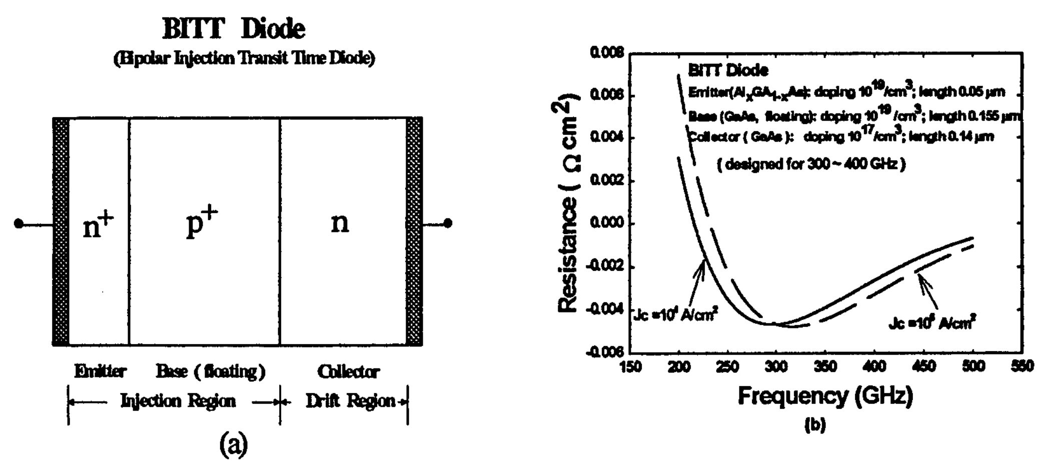


Figure 1 (a) A schematic structure for Bipolar Injection Transit Time Diode. (b) The specific negative small signal negative resistance of a BITT designed for 300-400 GHz